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Impact of Different Methods of Nano Fertilizers Application on Soil Chemical Properties and Fertility Status in Sunflower Growing Soils

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Abstract

Sunflower is an important oilseed crop, which is grown in different agro climatic zones of India. Nutrient management plays an important role in increasing seed yield and maintaining soil fertility status. In this view a field experiment was conducted at Zonal Agricultural Research Station, GKVK, Bengaluru during 2019 and 2020 to study the impact of different methods of nano fertilizers application on soil chemical properties and fertility status of soil. The experiment was laid out using RCBD with factorial concept with three replications. Pooled analysis indicated that, among different treatment combinations, the treatment seed priming with nano boron 1500 ppm (GsP) + foliar application of nano sulphur 600 ppm + nano boron 1500 ppm (GsP) recorded significantly higher seed yield (3588 kg ha^{-1}), However soil chemical properties (after harvest of the crop) namely pH, EC, soil organic carbon, organic matter and soil available nutrient status namely available N, P_2O_5, K_2O, S, B and Zn were found non significant with respect to different levels of seed priming and foliar application of nano fertilizers.

Keywords : Oilseed, Micronutrients, Seed treatment, Foliar application

Oil seeds plays an important role in agricultural economy of India. Oilseeds are important next only to food grains in terms of area, production and value. Among oilseed crops, Sunflower (*Helianthus annuus* L.) is an important annual oilseed crop, popularly known as 'Surajmukhi' or 'Sooryakanthi', belongs to family *Asteraceae*. Sunflower ranks third, next to groundnut and soybean in terms of total production of oilseeds in the world. It was cultivated on an area of 25.61 m. ha. with an annual production of 46.75 m t and productivity of 1,849 kg ha^{1} in the world. In India, sunflower was cultivated on an area of about 0.29 m. ha. with an annual production of 0.21 m t and productivity of 738 kg ha^{-1}. In Karnataka, sunflower was grown on an area of 0.20m. ha. with production of 0.99 m t and productivity of 529 kg ha^{-1} (Anonymous, 2019).

Intensification of Agricultural systems leads to increased negative effects at different scales, namely increased soil erosion, soil fertility decline and reduced biodiversity at the local level, depletion and pollution of groundwater and eutrophication of surface waters at the regional level and changes in atmospheric composition and climate on a global scale. For sustaining better soil quality under intensive systems of agriculture, the emphasis should be on developing of workable soil quality indicators and methods to assess and monitor soil quality, assessment of soil quality under different land use management systems (cropping system, tillage, water and nutrient use practices) and to identify the effect of management practices aggrading / degrading / sustaining soil quality. Emphasis on present day agriculture is to produce more with lesser land, water and man power. Considering the above factors with a growing world population there has been a growing interest to develop such management practices or tools which alone or in combination with crop management practices could ensure a good yield. For this seed treatment and foliar application with micronutrients are the major tools (Altaf Kuntoji & Subbarayappa, 2021).

Seed treatment is like baby care being with the mother and it ranges from a basic dressing to coating

and pelleting. It is done to control a variety of pests, diseases and to ensure uniform stand establishment by protecting against soil borne pathogens and insects.

To save the crop from nutrient loss, foliar nutrition with different nutrients at particular intervals has a vital place. The advantages of using foliar feeding of plants are quick plant response, small quantity of the nutrient, compensation for the lack of soil fixation, avoiding root uptake problems, increased yield and fiber quality in cotton. Foliar fertilization is actually a complement to soil fertilization.

Nanotechnology precisely detects and delivers the correct quantity of nutrients and pesticides that promote productivity while ensuring environmental safety and higher nutrient use efficiency. The nanotechnology can be exploited in the value chain of entire agriculture production system (Tarafdar *et al.,* 2012). Nanotechnology has provided feasibility of exploiting nanoscale nano structured materials as fertilizer carriers or controlled- release vectors for building of so- called 'smart fertilizer' as new facility to enhance nutrient use efficiency and reduce costs of environmental protection (Chinnamuthu and Boopathi, 2009). Hence experiment was conducted to know the impact of different methods of nano fertilizers application on soil chemical properties and fertility status in sunflower growing soils.

Material and Methods

A field experiment was conducted at Zonal Agricultural Research Station, GKVK, Bengaluru during 2019 and 2020 to know the impact of different methods of nano fertilizers application on soil chemical properties and nutrient status in sunflower growing soils. The experiment was laid out in Randomized Complete Block Design (Factorial concept) with two factors [Factor I (S - Seed treatment) S_1 : Seed priming with nano sulphur - 600 ppm (GsP*), S_2 : Seed priming with nano sulphur - 750 ppm (CP**), S_3 : Seed priming with nano boron - 1500 ppm (GsP) and S_4 : Seed priming with nano boron - 2000 ppm (CP)], [Factor II (F - foliar application of nutrients at ray floret stage) F_1 : Nano sulphur - 600 ppm (GsP), F_2 : Nano sulphur - 750 ppm (CP), F_3 : Nano boron - 1500 ppm (GsP), F_4 : Nano boron - 2000 ppm (CP), F_5 : Nano sulphur 600 ppm + Nano boron - 1500 ppm (GsP) and F_6 : Nano sulphur - 750 ppm + Nano boron - 2000 ppm (CP)] with two control C_1 : Recommended dose of fertilizers (RDF) only and C_2 : Recommended package of practices (RPP) treatments replicated thrice.

Note [GsP : Green synthesised nano particle; **CP : Commercially available nano particle; RDF : ($N:P_2O_5:K_2O$ 90:90 : 62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments; RPP : RDF + soil application of $ZnSO_4$ (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage].

Sunflower was sown in a plot size of 5.4 m × 4.8 m with a distance between row to row (60 cm) and plant to plant (30 cm). Soil characteristics of the experimental site were classified as fine, kaolinitic, isohyperthermic and Typic Kandiustalf as per USDA classification. The soil has 21 per cent moisture at field capacity and 12.8 per cent at permanent wilting point (PWP). The available water content of the soil is 10.46 cm for the first 90 cm depth. Soil characterization was done by following the Carter 1993 methods. Bulk density of the soil is about 1.59 to 1.42 Mg m^{-3}. Before sowing of sunflower and after harvesting of the crop the soil chemical properties and nutrient status were analysed and presented statistically.

Results and Discussion

The results of the field experiment conducted to know the impact of different methods of nano fertilizers application on soil chemical and nutrient status in sunflower growing soils were presented in Table 1 to 7. The initial soil characteristics of experimental site was presented in Table 1, seed yield (kg ha^{-1}) presented in Table 2 and soil chemical properties and nutrient status as affected by different methods of nano fertilizers application was presented in Table 3 to 7.

TABLE 1

Initial physical and chemical properties of the experimental site soil

Particulars	Value
Coarse sand (%)	52.4
Fine sand (%)	14.9
Silt (%)	15.9
Clay (%)	15.1
pH (1: 2.5 soil : water extract)	7.2
Electrical conductivity (dS m^{-1})	0.40
Organic carbon (g kg^{-1})	0.32
Organic matter (%)	0.55
Available nitrogen (kg ha^{-1})	326
Available phosphorus (kg ha^{-1})	29.8
Available potassium (kg ha^{-1})	298
Available zinc (mg kg^{-1})	1.22
Available boron (mg kg^{-1})	0.26
Available sulphur (mg kg^{-1})	7.11

Initially experimental site soil contains coarse sand (52.4 %), fine sand (14.9 %), silt (15.9 %) and clay (15.1 %) with neutral pH (7.2). But the soil was low in organic carbon (0.32 g kg^{-1}) and organic matter (0.99 %) content. Similarly with the available micronutrient status, because available zinc (1.22 mg kg^{-1}), available boron (0.26 mg kg^{-1}) and available sulphur (7.11 mg kg^{-1}) was recorded lesser content in the soil. Whereas, the initial nitrogen content was medium in availability (326 kg ha^{-1}) because of previous crop in 2019. In 2019, before sunflower was sown, the experimental site was with horsegram as a catch crop, due to nitrogen fixation of horsegram nitrogen content was medium and potassium content was also medium (298 kg ha^{-1}) but availability of phosphorus was low (29.8 kg ha^{-1}) during 2019.

The data on pH, EC, Soil organic carbon and organic matter of soil as influenced by seed priming and foliar application of different nano fertilizers were presented in Table 3 and 4. The soil parameters like pH, EC, Soil organic carbon and organic matter of soil did not show any significant difference between seed priming and foliar application of different nano fertilisers and their interactions as well as between all treatment combinations and control treatments. Elumalai and Velmurugan in 2015, recorded similar observations in red soils of Tamil Nadu, they also reported that higher buffering capacity of soils will resist the minute change in pH and EC.

The seed yield of sunflower recorded significant difference between seed priming and foliar application of different nano fertilisers and their interactions as well as between all treatment combinations and control treatments. Among seed priming with different nano fertilizers with different concentrations, the treatment seed priming with nano boron 1500 ppm (GsP) recorded significantly higher seed yield (2798, 2758 and 2778 kg ha^{-1} in 2019, 2020 and pooled data, respectively). Among foliar application of different nano fertilizers with different concentrations, the treatment received nano sulphur 600 ppm + nano boron 1500 ppm (GsP) recorded significantly higher seed yield (3419, 3389 and 3404 kg ha^{-1} in 2019, 2020 and pooled data, respectively). Among different treatment combinations, the treatment seed priming with nano boron 1500 ppm (GsP) + foliar application of nano sulphur 600 ppm + nano boron 1500 ppm (GsP) recorded significantly higher seed yield (3601, 3574 and 3588 kg ha^{-1} in 2019, 2020 and pooled analysis, respectively)

The soil available nitrogen, phosphorus, potassium, boron, sulphur and zinc of soil after harvest of the crop did not show any significant difference between seed priming and foliar application of different nano fertilisers and their interactions and also in control treatments. Rani, 2009 reported similar results with sunflower crop, they reported that seed treatment and foliar application of nano nutrients did not altered the soil nutrient status (Sudhakara and Krishnamurthy, 2021). Singh in 2008 reported that foliar application of nano nutrients did not influence much on soil chemical properties. Small quantity of nano particles application did not alters the soil chemical properties and inherent nutrient status of the soil (Chatterjee *et al*., 1985; Prasad *et al.,* 2012 and Patil *et al.,* 2006).

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TABLE 2

Seed yield of sunflower crop as influenced by different methods of nano fertilizer application

Treatments			2019	2020	Pooled data
Factor I : Seed priming (S)					
S_1 : Seed priming with nano sulphur-600 ppm (GsP*)			2710	2687	2699
S_2 : Seed priming with nano sulphur-750 ppm (CP**)			2588	2526	2557
S_3 : Seed priming with nano boron-1500 ppm (GsP)			2798	2758	2778
S_4 : Seed priming with nano boron-2000 ppm (CP)			2618	2608	2613
SEm ±			15.7	13.8	15.1
CD (P = 0.05)			50.4	46.2	48.6
Factor II : Foliar application (F) at ray floret stage					
F_1 : Nano sulphur-600 ppm (GsP)			2252	2210	2231
F_2 : Nano sulphur-750 ppm (CP)			2043	2039	2041
F_3 : Nano boron-1500 ppm (GsP)			2882	2861	2872
F_4 : Nano boron-2000 ppm (CP)			2408	2394	2401
F_5 : Nano sulphur 600 ppm + Nano boron-1500 ppm (GsP)			3419	3389	3404
F_6 : Nano sulphur-750 ppm + Nano boron-2000 ppm (CP)			3071	3038	3055
SEm ±			20.0	17.6	18.4
CD (P = 0.05)			65.8	57.9	60.2
Interaction : (S×F)					
$S_1 \times F_1$	S_1: Seed priming with nano sulphur 600 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	2242	2217	2230
$S_1 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	2109	2086	2098
$S_1 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	2886	2861	2874
$S_1 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	2436	2416	2426
$S_1 \times F_5$		F_5 : F_1 + F_3 (GsP)	3490	3459	3475
$S_1 \times F_6$		F_6 : F_2 + F_4 (CP)	3099	3076	3088
$S_2 \times F_1$	S_2: Seed priming with nano sulphur 750 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	2265	2251	2258
$S_2 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	1896	1879	1888
$S_2 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	2811	2784	2798
$S_2 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	2310	2291	2301
$S_2 \times F_5$		F_5 : F_1 + F_3 (GsP)	3241	3259	3250
$S_2 \times F_6$		F_6 : F_2 + F_4 (CP)	3010	2984	2997
$S_3 \times F_1$	S_3: Seed priming with nano boron 1500 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	2253	2235	2244
$S_3 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	2167	2151	2159
$S_3 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	2956	2937	2947
$S_3 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	2514	2499	2507
$S_3 \times F_5$		F_5 : F_1 + F_3 (GsP)	3601	3574	3588
$S_3 \times F_6$		F_6 : F_2 + F_4 (CP)	3194	3170	3182
$S_4 \times F_1$	S_4 : Seed priming with nano boron 2000 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	2248	2231	2240
$S_4 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	1999	1984	1992
$S_4 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	2875	2857	2866
$S_4 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	2374	2354	2364
$S_4 \times F_5$		F_5 : F_1 + F_3 (GsP)	3350	3328	3339
$S_4 \times F_6$		F_6 : F_2 + F_4 (CP)	2981	2957	2969
		SEm ±	24.8	21.3	23.8
		CD (P = 0.05)	78.8	67.2	75.8
Control plots: (C)					
C_1 : Recommended dose of fertilizers (RDF) only			1689	1649	1669
C_2 : Recommended package of practices (RPP)			1798	1742	1770
		SEm ±	29.6	28.5	29.1
		CD (P = 0.05)	94.5	87.6	90.7

*GsP: Green synthesised nano particle; **CP : Commercially available nano particle; RDF : ($N:P_2O_5:K_2O$ 90:90:62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments; RPP : RDF + Soil application of $ZnSO_4$ (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm ; (0.2%) at ray floret stage

TABLE 3

Chemical properties of soil after harvest of sunflower crop as influenced by different methods of nano fertilizer application

Treatments			pH			EC (dSm^{-1})		
			2019	2020	Pooled data	2019	2020	Pooled data
Factor I : Seed priming (S)								
S_1 : Seed priming with nano sulphur-600 ppm (GsP*)			7.1	6.9	7.0	0.38	0.35	0.37
S_2 : Seed priming with nano sulphur-750 ppm (CP**)			6.9	7.0	7.0	0.36	0.36	0.36
S_3 : Seed priming with nano boron-1500 ppm (GsP)			7.2	7.1	7.2	0.36	0.35	0.36
S_4 : Seed priming with nano boron-2000 ppm (CP)			7.1	7.2	7.2	0.38	0.35	0.37
SEm ±			0.5	0.4	0.5	0.04	0.03	0.04
CD (P = 0.05)			NS	NS	NS	NS	NS	NS
Factor II : Foliar application (F) at ray floret stage								
F_1 : Nano sulphur-600 ppm (GsP)			7.0	7.0	7.0	0.40	0.38	0.39
F_2 : Nano sulphur-750 ppm (CP)			6.9	7.1	7.0	0.33	0.35	0.34
F_3 : Nano boron-1500 ppm (GsP)			7.1	7.2	7.2	0.36	0.36	0.36
F_4 : Nano boron-2000 ppm (CP)			7.2	7.3	7.3	0.38	0.32	0.35
F_5 : Nano sulphur 600 ppm+Nano boron-1500 ppm (GsP)			7.4	7.0	7.2	0.40	0.34	0.37
F_6 : Nano sulphur-750 ppm+Nano boron-2000 ppm (CP)			7.2	7.1	7.2	0.35	0.40	0.38
SEm ±			0.6	0.5	0.5	0.05	0.04	0.05
CD (P = 0.05)			NS	NS	NS	NS	NS	NS
Interaction : (S×F)								
$S_1 \times F_1$	S_1: Seed priming with nano sulphur 600 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	6.8	6.8	6.8	0.36	0.33	0.35
$S_1 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	6.7	7.1	6.9	0.32	0.36	0.34
$S_1 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	7.1	7.0	7.1	0.35	0.32	0.34
$S^1 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	7.0	7.0	7.0	0.31	0.40	0.36
$S_1 \times F_5$		F_5 : F_1 + F_3 (GsP)	7.3	7.1	7.2	0.35	0.31	0.33
$S_1 \times F_6$		F_6 : F_2 + F_4 (CP)	7.2	7.2	7.2	0.28	0.40	0.34
$S_2 \times F_1$	S_2: Seed priming with nano sulphur 750 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	6.9	7.0	7.0	0.30	0.38	0.34
$S_2 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	6.7	6.9	6.8	0.31	0.36	0.34
$S_2 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	7.0	7.1	7.1	0.35	0.32	0.34
$S_2 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	6.9	6.8	6.9	0.35	0.31	0.33
$S_2 \times F_5$		F_5 : F_1 + F_3 (GsP)	7.2	7.1	7.2	0.36	0.33	0.35
$S_2 \times F_6$		F_6 : F_2 + F_4 (CP)	7.2	7.1	7.2	0.40	0.32	0.36
$S_3 \times F_1$	S_3: Seed priming with nano boron 1500 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	6.8	6.7	6.8	0.33	0.31	0.32
$S_3 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	6.7	6.7	6.7	0.36	0.35	0.36
$S_3 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	7.1	7.1	7.1	0.38	0.36	0.37
$S_3 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	7.0	7.0	7.0	0.40	0.28	0.34
$S_3 \times F_5$		F_5 : F_1 + F_3 (GsP)	7.5	7.5	7.5	0.35	0.31	0.33
$S_3 \times F_6$		F_6 : F_2 + F_4 (CP)	7.2	7.2	7.2	0.38	0.30	0.34
$S_4 \times F_1$	S_4 : Seed priming with nano boron 2000 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	7.2	7.3	7.3	0.35	0.29	0.32
$S_4 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	6.8	6.7	6.8	0.36	0.31	0.34
$S_4 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	6.7	6.7	6.7	0.32	0.36	0.34
$S_4 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	7.1	7.1	7.1	0.31	0.35	0.33
$S_4 \times F_5$		F_5 : F_1 + F_3 (GsP)	7.0	7.0	7.0	0.35	0.36	0.36
$S_4 \times F_6$		F_6 : F_2 + F_4 (CP)	7.2	7.1	7.2	0.36	0.36	0.36
SEm ±			0.7	0.6	0.7	0.06	0.05	0.06
CD (P = 0.05)			NS	NS	NS	NS	NS	NS
Control plots: (C)								
C_1 : Recommended dose of fertilizers (RDF) only			6.9	6.8	6.9	0.32	0.30	0.31
C_2 : Recommended package of practices (RPP)			7.0	7.0	7.0	0.35	0.34	0.35
SEm ±			0.7	0.6	0.7	0.07	0.06	0.07
CD (P = 0.05)			NS	NS	NS	NS	NS	NS

*GsP : Green synthesised nano particle and **CP : Commercially available nano particle RDF : ($N:P_2O_5:K_2O$ 90:90:62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments RPP : RDF + Soil application of $ZnSO_4$ (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage

TABLE 4

Organic carbon and organic matter content of soil after harvest of sunflower crop as influenced by different methods of nano fertilizer application

Treatments			Organic carbon (%)			Organic matter (%)		
			2019	2020	Pooled data	2019	2020	Pooled data
Factor I: Seed priming (S)								
S_1 : Seed priming with nano sulphur-600 ppm (GsP*)			0.21	0.22	0.22	0.36	0.38	0.37
S_2 : Seed priming with nano sulphur-750 ppm (CP**)			0.22	0.24	0.23	0.38	0.41	0.40
S_3 : Seed priming with nano boron-1500 ppm (GsP)			0.29	0.21	0.25	0.50	0.36	0.43
S_4 : Seed priming with nano boron-2000 ppm (CP)			0.20	0.24	0.22	0.34	0.41	0.38
SEm ±			0.02	0.01	0.02	0.01	0.02	0.02
CD (P = 0.05)			NS	NS	NS	NS	NS	NS
Factor II : Foliar application (F) at ray floret stage								
F_1 : Nano sulphur-600 ppm (GsP)			0.21	0.24	0.23	0.36	0.41	0.39
F_2 : Nano sulphur-750 ppm (CP)			0.23	0.23	0.23	0.40	0.40	0.40
F_3 : Nano boron-1500 ppm (GsP)			0.21	0.22	0.21	0.36	0.38	0.37
F_4 : Nano boron-2000 ppm (CP)			0.23	0.21	0.22	0.40	0.36	0.38
F_5 : Nano sulphur 600 ppm+Nano boron-1500 ppm (GsP)			0.28	0.21	0.25	0.48	0.36	0.42
F_6 : Nano sulphur-750 ppm+Nano boron-2000 ppm (CP)			0.26	0.23	0.25	0.45	0.40	0.42
SEm ±			0.03	0.02	0.03	0.05	0.04	0.04
CD (P=0.05)	NS NS		NS	NS	NS	NS		
Interaction : (S×F)								
$S_1 \times F_1$	S_1: Seed priming with nano sulphur 600 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	0.28	0.24	0.26	0.48	0.41	0.45
$S_1 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	0.22	0.21	0.22	0.38	0.36	0.37
$S_1 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	0.23	0.21	0.22	0.40	0.36	0.38
$S_1 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	0.24	0.24	0.24	0.41	0.41	0.41
$S_1 \times F_5$		F_5 : F_1 + F_3 (GsP)	0.25	0.23	0.24	0.43	0.40	0.41
$S_1 \times F_6$		F_6 : F_2 + F_4 (CP)	0.22	0.21	0.22	0.38	0.36	0.37
$S_2 \times F_1$	S_2: : Seed priming with nano sulphur 750 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	0.23	0.25	0.24	0.40	0.43	0.41
$S_2 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	0.22	0.22	0.22	0.38	0.38	0.38
$S_2 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	0.24	0.24	0.24	0.41	0.41	0.41
$S_2 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	0.26	0.21	0.24	0.45	0.36	0.41
$S_2 \times F_5$		F_5 : F_1 + F_3 (GsP)	0.27	0.21	0.24	0.47	0.36	0.41
$S_2 \times F_6$		F_6 : F_2 + F_4 (CP)	0.21	0.24	0.23	0.36	0.41	0.39
$S_3 \times F_1$	S_3: Seed priming with nano boron 1500 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	0.28	0.23	0.26	0.48	0.40	0.44
$S_3 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	0.28	0.21	0.25	0.48	0.36	0.42
$S_3 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	0.27	0.21	0.24	0.47	0.36	0.41
$S_3 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	0.24	0.27	0.26	0.41	0.47	0.44
$S_3 \times F_5$		F_5 : F_1 + F_3 (GsP)	0.25	0.24	0.25	0.43	0.41	0.42
$S_3 \times F_6$		F_6 : F_2 + F_4 (CP)	0.24	0.21	0.23	0.41	0.36	0.39
$S_4 \times F_1$	S_4 : Seed priming with nano boron 2000 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	0.22	0.20	0.21	0.38	0.34	0.36
$S_4 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	0.23	0.21	0.22	0.40	0.36	0.38
$S_4 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	0.22	0.26	0.24	0.38	0.45	0.41
$S_4 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	0.22	0.21	0.22	0.38	0.36	0.37
$S_4 \times F_5$		F_5 : F_1 + F_3 (GsP)	0.24	0.25	0.25	0.41	0.43	0.42
$S_4 \times F_6$		F_6 : F_2 + F_4 (CP)	0.24	0.21	0.23	0.41	0.36	0.39
SEm ±			0.04	0.03	0.40	0.07	0.05	0.06
CD (P = 0.05)			NS	NS	NS	NS	NS	NS
Control plots : (C)								
C_1 : Recommended dose of fertilizers (RDF) only			0.20	0.19	0.20	0.34	0.33	0.34
C_2 : Recommended package of practices (RPP)			0.21	0.22	0.22	0.36	0.38	0.37
SEm ±			0.05	0.04	0.05	0.09	0.07	0.08
CD (P = 0.05)			NS	NS	NS	NS	NS	NS

*GsP : Green synthesised nano particle and **CP : Commercially available nano particle RDF : ($N:P_2O_5:K_2O$ 90:90:62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments RPP : RDF + Soil application of ZnSO4 (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage

TABLE 5

Available nitrogen and phosphorus content of soil after harvest of sunflower crop as influenced by different methods of nano fertilizer application

Treatments			Available N (kg ha^{-1})			Available P_2O_5 (kg ha^{-1})		
			2019	2020	Pooled data	2019	2020	Pooled data
Factor I: Seed priming (S)								
S_1 : Seed priming with nano sulphur-600 ppm (GsP*)			284.9	238.4	261.7	79.4	111.7	95.6
S_2 : Seed priming with nano sulphur-750 ppm (CP**)			291.9	252.8	272.4	81.8	116.3	99.1
S_3 : Seed priming with nano boron-1500 ppm (GsP)			280.6	230.1	255.4	78.1	109.0	93.6
S_4 : Seed priming with nano boron-2000 ppm (CP)			288.9	246.4	267.7	80.2	113.0	96.6
SEm ±			5.7	5.5	5.6	1.8	1.7	1.8
CD (P = 0.05)			NS	NS	NS	NS	NS	NS
Factor II : Foliar application (F) at ray floret stage								
F_1 : Nano sulphur-600 ppm (GsP)			291.9	252.5	272.2	80.8	114.2	97.5
F_2 : Nano sulphur-750 ppm (CP)			297.3	262.8	280.1	81.2	115.1	98.2
F_3 : Nano boron-1500 ppm (GsP)			284.6	237.5	261.1	79.2	111.4	95.3
F_4 : Nano boron-2000 ppm (CP)			289.9	248.4	269.2	80.1	112.7	96.4
F_5 : Nano sulphur 600 ppm+Nano boron-1500 ppm (GsP)			277.9	224.4	251.2	77.6	108.1	92.9
F_6 : Nano sulphur-750 ppm+Nano boron-2000 ppm (CP)			282.7	233.2	258.0	79.0	110.9	94.9
SEm ±			6.4	6.3	6.3	2.1	1.9	1.9
CD (P = 0.05)			NS	NS	NS	NS	NS	NS
Interaction: (S×F)								
$S_1 \times F_1$	S_1: Seed priming with nano sulphur 600 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	294.6	257.7	276.2	82.0	117.5	99.8
$S_1 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	295.0	258.8	276.9	82.1	117.9	100.0
$S_1 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	289.6	247.3	268.5	80.3	113.3	96.8
$S_1 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	291.6	252.1	271.9	81.4	115.5	98.4
$S_1 \times F_5$		F_5 : F_1 + F_3 (GsP)	280.9	231.1	256.0	78.1	109.0	93.6
$S_1 \times F_6$		F_6 : F_2 + F_4 (CP)	287.2	242.4	264.8	79.4	111.4	95.4
$S_2 \times F_1$	S_2: Seed priming with nano sulphur 750 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	293.3	255.0	274.2	81.7	116.4	99.1
$S_2 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	295.9	260.1	278.0	82.1	118.3	100.2
$S_2 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	290.9	250.1	270.5	80.8	114.3	97.5
$S_2 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	292.9	254.2	273.6	81.7	116.2	99.0
$S_2 \times F_5$		F_5 : F_1 + F_3 (GsP)	284.8	237.7	261.3	78.8	110.2	94.5
$S_2 \times F_6$		F_6 : F_2 + F_4 (CP)	287.9	243.4	265.7	79.4	111.5	95.4
$S_3 \times F_1$	S_3: Seed priming with nano boron 1500 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	294.0	256.3	275.2	81.8	116.7	99.2
$S_3 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	294.9	258.4	276.7	82.0	117.6	99.8
$S_3 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	289.3	246.8	268.1	80.1	112.9	96.5
$S_3 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	291.2	251.0	271.1	81.2	115.0	98.1
$S_3 \times F_5$		F_5 : F_1 + F_3 (GsP)	274.9	218.1	246.5	76.1	104.9	90.5
$S_3 \times F_6$		F_6 : F_2 + F_4 (CP)	285.9	240.1	263.0	79.3	111.2	95.2
$S_4 \times F_1$	S_4 : Seed priming with nano boron 2000 ppm (CP)	F_1 :Nano sulphur-600 ppm (GsP)	294.3	256.9	275.6	81.9	116.9	99.4
$S_4 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	295.3	259.2	277.3	82.1	118.2	100.2
$S_4 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	290.3	248.8	269.6	80.5	113.6	97.0
$S_4 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	292.3	253.1	272.7	81.4	115.8	98.6
$S_4 \times F_5$		F_5 : F_1 + F_3 (GsP)	283.0	234.2	258.6	78.6	109.7	94.1
$S_4 \times F_6$		F_6 : F_2 + F_4 (CP)	288.9	246.1	267.5	79.6	111.9	95.8
SEm ±			8.6	8.5	8.4	2.9	2.7	2.8
CD (P = 0.05)			NS	NS	NS	NS	NS	NS
Control plots: (C)								
C_1 : Recommended dose of fertilizers (RDF) only			304.2	276.3	290.3	85.0	123.2	104.1
C_2 : Recommended package of practices (RPP) 297.5			263.4	280.5	82.8	118.9	100.8	
SEm ±			9.2	9.1	9.1	3.6	3.5	3.6
CD (P = 0.05)			NS	NS	NS	NS	NS	NS

*GsP : Green synthesised nano particle and **CP : Commercially available nano particle RDF : ($N:P_2O_5:K_2O$ 90:90:62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments RPP : RDF + Soil application of ZnSO4 (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage

TABLE 6

Available potassium and sulphur content of soil after harvest of sunflower crop as influenced by different methods of nano fertilizer application

Treatments			Available K_2O (kg ha^{-1})			Available sulphur (ppm)		
			2019	2020	Pooled data	2019	2020	Pooled data
Factor I : Seed priming (S)								
S_1 : Seed priming with nano sulphur - 600 ppm (GsP*)			270.4	239.6	255.0	9.6	8.9	9.3
S_2 : Seed priming with nano sulphur - 750 ppm (CP**)			272.0	242.7	257.4	10.4	9.7	10.0
S_3 : Seed priming with nano boron - 1500 ppm (GsP)			268.2	235.2	251.7	11.6	10.9	11.3
S_4 : Seed priming with nano boron - 2000 ppm (CP)			270.9	240.3	255.6	12.8	11.9	12.3
SEm ±			5.1	4.8	5.1	1.2	1.1	1.1
CD (P = 0.05)			NS	NS	NS	NS	NS	NS
Factor II : Foliar application (F) at ray floret stage								
F_1 : Nano sulphur-600 ppm (GsP)			271.2	241.1	256.2	10.1	9.6	9.8
F_2 : Nano sulphur-750 ppm (CP)			272.1	242.8	257.5	11.0	10.1	10.5
F_3 : Nano boron-1500 ppm (GsP)			269.7	238.1	253.9	11.7	10.8	11.3
F_4 : Nano boron-2000 ppm (CP)			270.4	239.5	254.9	12.5	11.9	12.2
F_5 : Nano sulphur 600 ppm+Nano boron-1500 ppm (GsP)			266.6	231.9	249.3	9.1	8.3	8.7
F_6 : Nano sulphur-750 ppm+Nano boron-2000 ppm (CP)			269.0	236.7	252.9	9.9	9.4	9.6
SEm ±			7.4	7.3	7.3	1.5	1.4	1.4
CD (P = 0.05)			NS	NS	NS	NS	NS	NS
Interaction : (S×F)								
$S_1 \times F_1$	S_1: Seed priming with nano sulphur 600 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	273.9	246.6	260.2	12.9	12.9	12.9
$S_1 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	274.2	247.1	260.7	13.0	13.2	13.1
$S_1 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	270.5	239.7	255.1	11.2	10.4	10.8
$S_1 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	271.6	241.9	256.8	12.3	11.5	11.9
$S_1 \times F_5$		F_5 : F_1 + F_3 (GsP)	268.1	234.9	251.5	9.1	8.2	8.6
$S_1 \times F_6$		F_6 : F_2 + F_4 (CP)	269.6	237.8	253.7	10.3	9.4	9.9
$S_2 \times F_1$	S_2: Seed priming with nano sulphur 750 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	272.8	244.3	258.5	12.6	12.1	12.4
$S_2 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	274.4	247.6	261.0	13.1	13.5	13.3
$S_2 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	271.0	240.7	255.9	11.8	10.8	11.3
$S_2 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	272.3	243.3	257.8	12.6	11.9	12.3
$S_2 \times F_5$		F_5 : F_1 + F_3 (GsP)	269.2	237.0	253.1	9.8	8.8	9.3
$S_2 \times F_6$		F_6 : F_2 + F_4 (CP)	269.8	238.2	254.0	10.3	9.5	9.9
$S_3 \times F_1$	S_3: Seed priming with nano boron 1500 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	273.2	245.1	259.2	12.7	12.3	12.5
$S_3 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	274.0	246.9	260.5	13.0	12.9	12.9
$S_3 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	270.2	239.0	254.6	11.1	10.1	10.6
$S_3 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	271.4	241.4	256.4	12.1	11.2	11.7
$S_3 \times F_5$		F_5 : F_1 + F_3 (GsP)	264.8	228.3	246.5	7.6	7.6	7.6
$S_3 \times F_6$		F_6 : F_2 + F_4 (CP)	269.4	237.4	253.4	10.2	9.3	9.7
$S_4 \times F_1$	S_4 : Seed priming with nano boron 2000 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	273.4	245.7	259.6	12.8	12.4	12.6
$S_4 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	274.3	247.3	260.8	13.0	13.5	13.3
$S_4 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	270.8	240.3	255.5	11.4	10.5	11.0
$S_4 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	271.8	242.3	257.1	12.3	11.8	12.0
$S_4 \times F_5$		F_5 : F_1 + F_3 (GsP)	268.8	236.2	252.5	9.5	8.6	9.0
$S_4 \times F_6$		F_6 : F_2 + F_4 (CP)	269.9	238.5	254.2	10.5	9.7	10.1
SEm ±			9.8	9.6	9.7	2.1	1.9	1.9
CD (P = 0.05)			NS	NS	NS	NS	NS	NS
Control plots : (C)								
C_1 : Recommended dose of fertilizers (RDF) only			277.9	254.5	266.2	18.7	17.9	18.3
C_2 : Recommended package of practices (RPP)			274.5	247.7	261.1	13.7	13.5	13.6
SEm ±			12.3	12.1	12.2	2.9	2.7	2.8
CD (P = 0.05)			NS	NS	NS	NS	NS	NS

*GsP: Green synthesised nano particle and **CP : Commercially available nano particle; RDF : ($N:P_2O_5:K_2O$ 90:90:62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments; RPP : RDF + Soil application of ZnSO4 (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage

TABLE 7

Available boron and zinc content of soil after harvest of sunflower crop as influenced by different methods of nano fertilizer application

Treatments			Available K_2O (kg ha^{-1})			Available zinc (ppm)		
			2019	2020	Pooled data	2019	2020	Pooled data
Factor I : Seed priming (S)								
S_1 : Seed priming with nano sulphur-600 ppm (GsP*)			0.41	0.32	0.36	0.60	0.42	0.51
S_2 : Seed priming with nano sulphur-750 ppm (CP**)			0.50	0.40	0.45	1.04	0.84	0.94
S_3 : Seed priming with nano boron-1500 ppm (GsP)			0.35	0.27	0.31	0.26	0.10	0.18
S_4 : Seed priming with nano boron-2000 ppm (CP)			0.43	0.33	0.38	0.75	0.55	0.65
SEm ±			0.05	0.04	0.05	0.10	0.09	0.08
CD (P = 0.05)			NS	NS	NS	NS	NS	NS
Factor II: Foliar application (F) at ray floret stage								
F_1 : Nano sulphur-600 ppm (GsP)			0.46	0.36	0.41	0.85	0.66	0.75
F_2 : Nano sulphur-750 ppm (CP)			0.49	0.39	0.44	1.10	0.91	1.00
F_3 : Nano boron-1500 ppm (GsP)			0.42	0.34	0.38	0.54	0.36	0.45
F_4 : Nano boron-2000 ppm (CP)			0.44	0.34	0.39	0.69	0.50	0.60
F_5 : Nano sulphur 600 ppm+Nano boron-1500 ppm (GsP)			0.33	0.25	0.29	0.59	0.55	0.57
F_6 : Nano sulphur-750 ppm+Nano boron-2000 ppm (CP)			0.39	0.31	0.35	0.40	0.21	0.30
SEm ±			0.06	0.05	0.05	0.18	0.17	0.17
CD (P = 0.05)			NS	NS	NS	NS	NS	NS
Interaction: (S×F)								
$S_1 \times F_1$	S_1: Seed priming with nano sulphur 600 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	0.60	0.53	0.56	0.90	0.80	0.85
$S_1 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	0.61	0.55	0.58	1.10	0.90	1.00
$S_1 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	0.48	0.39	0.43	0.76	0.56	0.66
$S_1 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	0.52	0.43	0.47	1.01	0.82	0.91
$S_1 \times F_5$		F_5 : F_1 + F_3 (GsP)	0.37	0.28	0.33	0.25	0.06	0.16
$S_1 \times F_6$		F_6 : F_2 + F_4 (CP)	0.44	0.34	0.39	0.56	0.37	0.47
$S_2 \times F_1$	S_2: Seed priming with nano sulphur 750 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	0.57	0.49	0.53	1.12	1.11	1.12
$S_2 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	0.64	0.57	0.60	1.11	1.10	1.11
$S_2 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	0.50	0.40	0.45	0.88	0.70	0.79
$S_2 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	0.55	0.46	0.50	1.13	0.95	1.04
$S_2 \times F_5$		F_5 : F_1 + F_3 (GsP)	0.42	0.32	0.37	0.46	0.28	0.37
$S_2 \times F_6$		F_6 : F_2 + F_4 (CP)	0.45	0.35	0.40	0.60	0.41	0.50
$S_3 \times F_1$	S_3: Seed priming with nano boron 1500 ppm (GsP)	F_1 : Nano sulphur-600 ppm (GsP)	0.58	0.50	0.54	1.05	1.02	1.04
$S_3 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	0.61	0.54	0.57	0.90	0.80	0.85
$S_3 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	0.47	0.37	0.42	0.68	0.49	0.58
$S_3 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	0.51	0.41	0.46	0.95	0.76	0.86
$S_3 \times F_5$		F_5 : F_1 + F_3 (GsP)	0.29	0.19	0.24	0.75	0.70	0.73
$S_3 \times F_6$		F_6 : F_2 + F_4 (CP)	0.43	0.34	0.38	0.52	0.33	0.42
$S_4 \times F_1$	S_4 : Seed priming with nano boron 2000 ppm (CP)	F_1 : Nano sulphur-600 ppm (GsP)	0.59	0.51	0.55	1.11	1.10	1.11
$S_4 \times F_2$		F_2 : Nano sulphur-750 ppm (CP)	0.63	0.57	0.60	0.80	0.70	0.75
$S_4 \times F_3$		F_3 : Nano boron-1500 ppm (GsP)	0.49	0.39	0.44	0.83	0.65	0.74
$S_4 \times F_4$		F_4 : Nano boron-2000 ppm (CP)	0.54	0.45	0.50	1.05	0.88	0.96
$S_4 \times F_5$		F_5 : F_1 + F_3 (GsP)	0.39	0.29	0.34	0.38	0.19	0.28
$S_4 \times F^6$		F_6 : F_2 + F_4 (CP)	0.46	0.36	0.41	0.64	0.45	0.54
SEm ±			0.08	0.07	0.08	0.24	0.23	0.21
CD (P = 0.05)			NS	NS	NS	NS	NS	NS
Control plots : (C)								
C_1 : Recommended dose of fertilizers (RDF) only			0.72	0.64	0.68	1.11	1.02	1.07
C_2 : Recommended package of practices (RPP)			0.65	0.57	0.61	0.90	0.80	0.85
SEm ±			0.1	0.08	0.09	0.29	0.28	0.28
CD (P = 0.05)			NS	NS	NS	NS	NS	NS

*GsP: Green synthesised nano particle and **CP : Commercially available nano particle; RDF : ($N:P_2O_5:K_2O$ 90:90:62.5 kg ha^{-1}) + Farm yard manure (7.5 t ha^{-1}) common for all treatments ; RPP : RDF + Soil application of $ZnSO_4$ (10 kg ha^{-1}) and Borax (15 kg ha^{-1}) + Foliar application of borax 2000 ppm (0.2%) at ray floret stage

Seed treatment and foliar application of different nano fertilizers in sunflower crop enhances seed yield of sunflower crop. But these nano fertilizers did not influence the soil chemical and nutrient status. Buffering capacity of soil resists the minute changes in the chemical properties and application of nano fertilizers in lesser quantity did not show any significant difference on soil chemical properties and nutrient status of soil between seed priming and foliar application of different nano fertilisers and their interactions in control treatments. Application of nano fertilizers in minute quantity improves crop growth and reduces environmental pollution.

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